Conodonts, Corals and Stromatoporoids from Subsurface Lower Devonian in the Northparkes Porphyry District of Central Western New South Wales and their Regional Stratigraphic Implications

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Documented in this report is a small fauna recovered from an unnamed stratigraphic unit of bioclastic limestone, black shale and carbonaceous mudstone intersected in a drill hole (NPM-GD871) undertaken by CMOC-Northparkes Mines in the Northparkes porphyry district, located ca 30 km NW of Parkes, central western New South Wales. It includes six conodont species (*Panderodus unicostatus, Pandorinellina exigua, Pelekysgnathus* sp., *Wurmiella excavata, Zieglerodina remscheidensis* and gen. et sp. indet.), one rugose coral (*Microplasma ronense*), three tabulate coral species (*Favosites duni, Squameofavosites bryani* and *Thamnopora minor*) and one stromatoporoid species (*Densastroma* sp.). Faunal analysis indicates a maximum age of late Lochkovian and a minimum age of Pragian for this unit, equivalent to the upper part of the Derriwong Group. The fauna is also comparable with those recovered from the Jerula Limestone Member of the Gleninga Formation (upper part of the Yarra Yarra Creek Group) exposed farther west. Conodont data documented here suggest that the base of the Derriwong Group is diachronous across the region, and on the eastern flank of the Tullamore Syncline has a minimum age of the late Pragian rather than early Lochkovian as currently accepted.

INTRODUCTION

The Northparkes porphyry district, located ca 30 km northwest of the rural centre of Parkes, central western New South Wales, is a region of national metallogenic importance (Fig. 1). The porphyry Cu-Au deposits are related to Ordovician monzonitic intrusive complexes within the region. The study area is within the Pearce Prospect that lies ca 9 km northwest of the current Northparkes (CMOC) mining operations on the northern side of the Bogan River in the northernmost reaches of the Northparkes exploration lease EL5801 (Fig.1). The Pearce Prospect was first delineated by Hooper (1992), then by Arundell et. al. (1997) and Morris et. al. (1999).

The topography of the area is a flat lying gilgai with some overbank deposits from the Bogan River, aeolian transported cover, and float sourced from the low relief hills to the west. The area is currently used for both cropping and grazing, with much of the native vegetation removed. With sparse, shallow drilling and no outcrop, geology until recently has been defined by logging of reverse circulation drilling chips and geophysics and is still comparatively poorly understood. Therefore, any new data will advance the understanding of the geological history, and potentially inform the formation, distribution and preservation of the Cu-Au mineral deposits in this area. We report herein details of Early Devonian conodonts recovered from three limestone samples, and rugose and tabulate
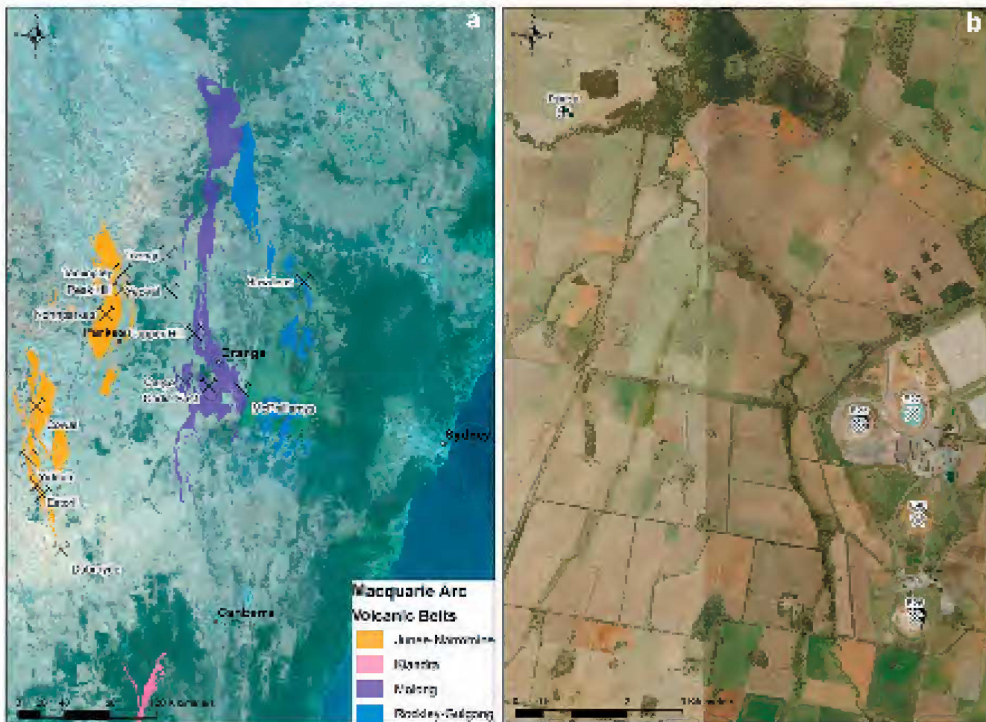
Figure 1. Location maps; a, map showing locations of Northparkes and other major mining sites of the porphyry copper-gold deposits in the Macquarie Volcanic Province of central western New South Wales; b, map showing the locations of the operational mining sites of CMOC-Northparkes Mines and the location of the drill hole NPM-GD871 within the Pearce Prospect (Spatial Services, Department of Finance, Services and Innovation New South Wales, 2019).

corals and stromatoporoids associated with one of the samples from drill hole NPM-GD871. The age of the 35 m of bioclastic limestone, black shale and carbonaceous mudstone in this drill hole, and their unconformable contact with the underlying volcanic rocks, are crucial to the increased understanding of local and regional stratigraphy discussed below.

REGIONAL GEOLOGY

The Macquarie Arc (Fig. 1; Glen et al., 2007; Fergusson, 2014) of eastern Australia comprises four fault-limited belts of mafic to intermediate volcanics, volcanoclastics, and limestones, and calc-alkaline to shoshonitic intrusive rocks. These four belts of the Macquarie Arc occur within Ordovician to early Silurian turbidite sequences that comprise the majority of the Lachlan Fold Belt, which extends from far northern Queensland to eastern Tasmania (Krynen et al., 1990; Gray and Foster, 2004; Crawford

et al., 2007b). The Macquarie Arc is interpreted to have formed above an Ordovician to earliest Silurian intra-oceanic supra-subduction zone (Percival and Glen, 2007; Glen et al., 2012), and accreted to the eastern margin of Australia during the Benambran Orogeny (Crawford et al., 2007a). Mechanisms for the development and segmentation of the arc remain contentious (Fergusson and Coney, 1992; Fergusson and Fanning, 2002; Meffre et al., 2007; Cayley, 2011; Moresi et al., 2014; Rawlinson et al., 2014; Fergusson and Henderson, 2015; Pilia et al., 2015).

Large tonnage mineralisation in the Macquarie Arc is associated with silica-saturated alkalic and calc-alkalic porphyries, and related high sulfidation, skarn and carbonate-base-metal epithermal deposits (Cooke et al., 2007; Lickfold et al., 2007). High-grade mineralisation at Northparkes is linked to small volume, oxidised, evolved shoshonitic magmas (~444–435 Ma; Cooke et al., 2007; Lickfold et al., 2007; Pacey et al., 2019).

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The Northparkes porphyry district straddles the Forbes Anticline that extends with a north-south axis between the Tullamore Syncline to the west and the Hervey Syncline to the east (Sherwin, 1996, fig. 5). Outcrops of Siluro-Devonian rocks are very rare in this district, and are only observed close to the Ordovician Wombin and Goonumbla Volcanics around the Wombin State Forrest (Krynen et al., 1990). However, the Derriwong and Wallingalair groups of late Silurian to Early Devonian age are exposed to the immediate west of the Northparkes porphyry district, on the eastern flank of the Tullamore Syncline, where the predominantly coarse grained thick-bedded quartzose sandstones and conglomerates of the Wallingalair Group form low ridges. In contrast the Cookeys Plains Formation of the Derriwong Group is dominated by shale, siltstone and fine-grained sandstone with scattered and poorly exposed outcrop. Structure in the area is poorly constrained due to the extent of Quaternary cover and the depth of weathering. The dip of Ordovician rocks in the district is variable but tends to be ca 60°E while the overlying Devonian rocks near the Pearce Prospect have an approximately 30° dip to the southeast.

Studies of the geology of the Northparkes district have focused on the porphyry mineralisation, the Ordovician Goonumbla Volcanic Complex and the numerous monzonitic intrusive rocks related to the porphyry Cu-Au mineralisation (Lickfold et al., 2003, 2007; Simpson et al., 2005; Cooke et al., 2007; Pacey et al., 2019). The Ordovician rocks that are the subject of numerous government and Ph.D. studies are overlain by the comparatively poorly studied Siluro-Devonian sedimentary rocks of the Derriwong Group (Sherwin, 1996; Lyons, 2000).

SAMPLED DRILL CORE SECTION AND MATERIAL

A 2018 drill campaign of CMOC-Northparkes Mines intersected bioclastic limestones, black shale and carbonaceous mudstone in contact with altered volcanic rocks in one of two drill holes at the Pearce prospect (NPM-GD871 at 32°51'38.18629"S, 147°58'54.03845") (Fig. 1b). Along with aircore and reverse circulation drilling they provide the only information for the subsurface (Fig. 2). For the purpose of this report, stratigraphic logs of the drill holes have been created from the detailed original logging notes (Table 1). No detailed petrographic work has been undertaken to refine the initial classification of the lithologies. Rocks intersected in these drill holes are visually unlike the Ordovician

Wombin and Goonumbla volcanics as defined within the Northparkes mining operations, on which the original logging method was based.

Quaternary cover at the Pearce Prospect (Krynen et al., 1990; Sherwin, 1996) (Litho-units 1 and 2) is at least 2–3 m thick. It comprises sub-angular to sub-rounded quartz grains in a generally upward-fining sequence, with evidence of a basal conglomerate at 41 m in GD870 that may represent a palaeochannel (Fig. 2, Table 1). Separating transported cover from the underlying regolith is complex due to the abundance of cracking clays, the reworking of the cover by farming practices and the often deep gilgai. The saprolith profile (Litho-unit 3, Table 1) under the Quaternary cover is interpreted to be a product of weathering of Devonian rocks. The regolith and saprolith profile at the Pearce prospect are substantial, up to 35 m thick and dominated by sedimentary rocks (Litho-unit 3, Fig. 2, Table 1). Based on the abundance of rounded quartz, they might be sourced from the Late Devonian Hervey Group. At the base of complete oxidation (BOCO) in drill hole NPM-GD871 (66.1 m, Fig. 2) there are variably fossiliferous detrital limestones and interbedded siltstones of an unnamed unit. From 66 m to 91 m in NPM-GD871 there are carbonaceous mudstone and shale (Litho-unit 4, conodont samples C3005 and C3006) and detrital limestones (Litho-unit 5, conodont sample C3004) containing crinoid stems, and the stromatoporoids and tabulate corals that are documented in this report. The depositional environment is inferred to be below wave base but proximal to a shallow marine setting: either a lagoon, or a fringing reef in an emergent island arc setting (Table 1).

From 91 to 99m in NPM-GD871 a selective (chlorite-sericite-illite?) altered, moderately sorted, polymict, diorite/andesite clast-dominated breccia with a muddy calcareous matrix is present. An erosional contact is inferred between the fossiliferous beds (Litho-unit 5) and the underlying volcanics (Litho-unit 13), based on the distinct lack of metasomatism in the overlying carbonaceous rocks or in the breccia matrix (Litho-unit 6), despite pervasive alteration in the volcanics. No evidence of submarine emplacement of the volcanics is present suggesting deposition occurred on previously emergent rocks with an auto-brecciated or rubbly carapace. There is no evidence of a fault at this key contact. The nature of the erosional contact is complex, based on the lack of a significant contact in hole GD870. Given that the regional dip of Siluro-Devonian rocks is ca 30° to the SE, the contact should appear at or towards the top of GD870. The lack of fossiliferous rocks or any significant sedimentary strata in GD870 is further

Figure 2. Stratigraphic columns and correlation of the drill core sections (NPM-GD871 and NPM-GD870), and sample horizons from the unnamed Early Devonian carbonate unit in the NPM-GD871 drill core section; f1 = stratigraphic horizon for sample C3005, f2 = stratigraphic horizon for sample C3005, f3 = stratigraphic horizon for sample C3004 and associated corals and stromatoporoids (MMF46838 to MMF46844).

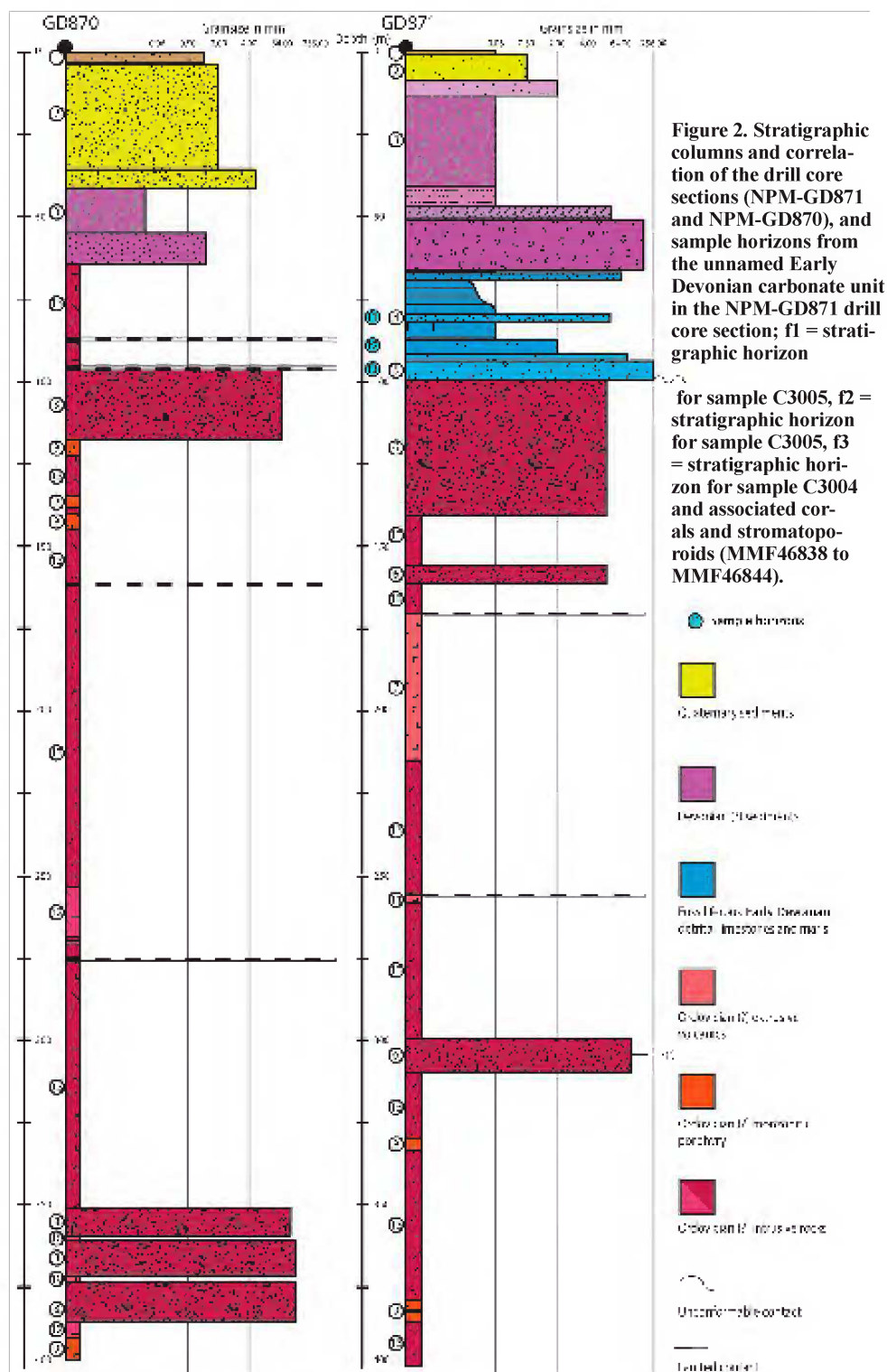**Table 1. Log of the drill core sections and lithostratigraphy**

Litho- unit	Apparent thickness	Lithology	Interpretation
1	1-3m (full profile)	Quaternary soils.	Aeolian transported cover and overbank fluvial deposits from the ephemiral Bogan River.
2	8 - 37 m	Well sorted quartz-rich oxidised sandy-clay. Sub-round quartz grains are abundant. Lower 6 m in GD870 is a poorly sorted quartz, lithic fragment rich conglomerate.	Basal conglomerate to an extensive transported Devonian cover sequence.
3	17-38 m	Detextured regolith and saprolith profile, transitions into saprock in last ~2 m of the interval.	Insitu weathered Devonian sediments.
4	27 m	Upward fining bedded carbonaceous black shale with minor fossil content.	Low energy marine facies, product of attrition of an overlying reef into a transitional marine setting well below wave base.
5	8m	Bioclastic limestone unconformablly overlying altered extrusive (?) volcanics.	Either an erosional contact based on clasts of altered volcanics in the matrix, or deposition on the autobrecciated carapace of a lava flow.
6	~2 - 40 m	Pervasive chlorite altered diorite breccia. Bornite at 120 m depth in GD871 is hosted in a epidote-chlorite + hematite alteration altered, silica cemented breccia	Tectonic breccia that has later become a conduit for later intrusive phases.
7	50 m	Crystal crowded plagioclase phyric trachyandesite. Mafics are magnetite, biotite and hornblende, with rare quartz eyes	Extrusive volcanics or a feeder dike related to lavas.
8	8 - 20m	Polymict diorite, trachyandesite, monzonite porphry clast breccia. Monzonite porphry clasts contain xenoliths of diorite and have chilled margins similar to aplite dykes.	Magmatic breccia, late monzonite porphry is interpreted to be the progenitor to this breccia facies.
9	<3-7m	Plagioclase-hornblende-biotite-titanite phyric monzonite porphry. Contacts are typically sharp intrusive but are infrequenetly faulted.	Late intrusive phase, hydrous but shows no evidence of significant mineralisation.
10	2 - 3 m	Trachyandesite - basaltic trachyandesite, fine grained to aphanitic groundmass of feldspar, maroon hematite dusting is overprinted by pervasive epidote-chlorite alteration. Mafics occur as radial growths.	extrusive volcanics or a feeder dike related to lavas.

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Table 1 continued

Litho- unit	Apparent thickness	Lithology	Interpretation
11	7 m	Cryptic volcanic lava flow or a tuff/fiamme breccia. Aphanitic to very fine grained crystal rich groundmass. Plagioclalse phenocrysts are partially sericitised. Anhydrite filled voids could be vesicles or fiamme.	Petrographic work is required to refine the paragenesis and association of this facies.
12	5 m	Alkali feldspar granite. K-feldspar phenocrysts <20 mm in size have a poikiolitic texture. Variably chloritised mafics include magnetite with biotite, pyroxene and minor hornblende. Lithology is hematite dusted with patchy epidote. Chilled margins at contact between AFG and diorite (13).	Similar to alkali feldspar obsereved in the Northparkes porphry district. Chilled margins at the contact between AFG and diorite provide a paragentic relationship
13	>250 m	Diorite, with a groundmass of interlocking plagioclase. Mafics are pyroxene, amphibole, biotite and blebs of magnetite. Mafics are variably altered to chlorite. Alteration assemblages and intensity vary from unaltered to intense pervasive epidote alteration. Short intervals of albitic and potassic alteration occur near contacts with other intrusive phases 6 and 7.	Cryptic diorite that requires petrographic and geochronolgical refinement as nothing similar is observed in the Northparkes district or regional exploration. Infered to be Ordovician (?).

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support for the transitional shallow to deep marine settings.

Based on geochemical similarities, the initial interpretation of the altered volcanics in NPM-GD871 and comparatively unaltered volcanics in GD870 (Lithounits 9-13) are equivalent to the Late Ordovician Wombin Volcanics. Further refinement would require U-Pb dating of zircons or other dateable mineral phases as well as petrographic analysis, which is beyond the scope of the present study. The extensive diorite intrusion logged in GD870 is unusual in the Northparkes district. However, late mafic finger dykes are a common feature in the Northparkes district and are seen cross-cutting the dioritic intrusion in GD870. The unusual monzonitic intrusions and small basaltic trachyandesites (Litho-unit 10) in NPM-GD871 are more typical of the Northparkes intrusive complex of Late Ordovician age, and have a geochemical signature associated with mineralising intrusions at Northparkes. The geochemistry indicates that the bioclastic limestones unconformably overlie mafic to intermediate volcanics similar to the Wombin Volcanics rather than the more felsic Devonian volcanics.

Material studied in this contribution includes a total of 35 identifiable conodont specimens, recovered from three samples (2 specimens in C3004, 25 in C3005 and 9 in C3006) representing the carbonate intervals in the NPM-GD871 drill core section (Fig. 2). Sample C3004 from the detrital limestone (Litho-unit 5) yielded only two conodont specimens but contained abundant macrofossils, which were also examined from 13 thin sections prepared from three levels (MMF46838 and MMF46839 from a depth of 90.8-90.9 m; MMF46840, MMF46841 and MMF46842 from 90.4-90.6 m; MMF46843 and MMF 46844 from 96.0-96.38 m). The conodonts from these three samples have a CAI of 4, indicating a burial temperature of 190 to 300 °C.

METHODS AND REPOSITORY

The larger core sample from depth 90.4 to 96.38 m in NPM-GD871 was selected for preparation of coral and stromatoporoid thin sections, before several pieces with less macrofossil material were selected (C3004) for the acid-leaching process. All the three limestone samples including C3004 (0.45 kg), C3005 (2.3 kg) and C3006 (1.85 kg), were dissolved in 10% acetic acid. The resulting insoluble residues were separated using sodium polytungstate solution. Conodonts illustrated in Figure 3 are SEM photomicrographs captured digitally (numbers with

the prefix IY are the file names of the digital images filed with GSNSW image database). In total, 36 conodont specimens are figured and bear the prefix MMMC (MMMC05550 to MMMC05585 inclusive). They are deposited in the microfossil collection, and corals (Figs 4–8) and stromatoporoids (Fig. 9) in the macrofossil collection (MMF46838 to MMF46844), of the Geological Survey of New South Wales, housed at the WB Clarke Geoscience Centre at Londonderry in outer western Sydney. For comparison and to assist regional biostratigraphic correlation, additional conodont specimens from the area to the east of Bogan Gate are illustrated in Figures 10–11.

EARLY DEVONIAN CONODONT FAUNA

Three samples processed have yielded six conodont taxa in the fauna, only five are identifiable, comprising *Panderodus unicostatus* (Branson and Mehl, 1933) (Fig. 3j–m), *Pandorinellina exigua* (Philip, 1966) (Fig. 3h–i), *Pelekysgnathus* sp. (Fig. 3n), *Wurmiella excavata* (Branson and Mehl, 1933) (Fig. c–f), *Zieglerodina remscheidensis* (Ziegler, 1960) (Fig. 3a–b) and gen. et sp. indet. (Fig. 3g). However, the stratigraphical interval bearing corals and stromatoporoids discussed in the following section yielded only a single conodont species, *P. unicostatus,* from sample C3004. Samples C3005 and C3006 produced the identical conodont assemblages, suggesting an Early Devonian (latest Lochkovian to Pragian) age. Among the four specifically identifiable species recovered, *P. unicostatus* has a relatively long stratigraphic range, extending through the entire Silurian into the Lower Devonian, and *W. excavata* has been reported from the lower Silurian to Lower Devonian (Corradini and Corriga, 2010). The Pa element of *Z. remscheidensis* is characterized by having uneven denticulation, a large cusp and a higher distal end of the anterior blade with several larger denticles (Fig. 3a). It has a stratigraphic range restricted to uppermost Silurian (Přídolí) to Middle Devonian (Peavey, 2013).

Pandorinellina exigua differs from other known species of the genus in having a markedly higher anterior third of the blade of the Pa element, which has the posterior-most denticle larger and higher with its posterior edge extending normal to the basal margin. It has been split into two subspecies, *P. exigua exigua* (Philip, 1966) and *P. exigua philipi* (Klapper, 1969), and both are recognized as cosmopolitan with a combined stratigraphic range from latest Lochkovian (the *pesavis* Biozone) to Emsian (the *patulus* Biozone). *Pandorinellina exigua philipi*
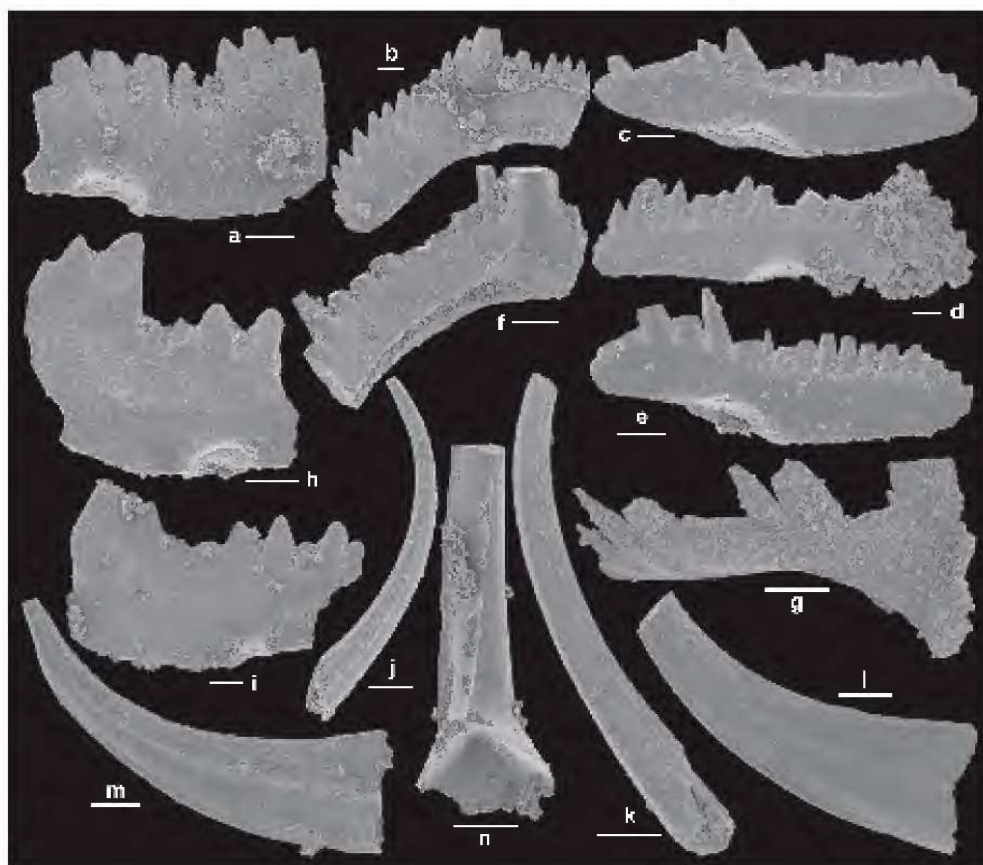
Figure 3. Early Devonian conodonts recovered from three samples (C3004, C3005 and C3006) in the unnamed stratigraphic unit intersected in the NPM-GD871 drill hole; a–b, *Zieglerodina remscheidensis* (Ziegler, 1960) from sample C3005; a, Pa element, MMMC05550, outer-lateral view (IY381-002); b, Pb element; MMMC05551, inner-lateral view (IY381-001); c–g, *Wurmiella excavata* (Branson and Mehl, 1933); c–e, Pa element; c, MMMC05552, sample C3005, outer-lateral view (IY381-004); d, MMMC05553, sample C3006, outer-lateral view (IY381-009); e, MMMC05554, sample C3005, inner-lateral view (IY381-003). f, M element, MMMC05555, sample C3005, posterior view (IY381-005); g, gen. et sp. indet., Sc element, MMMC05556, sample C3006, inner-lateral view (IY381-008); h-i, *Pandorinellina exigua* (Philip, 1966); Pa element; h, MMMC05557, sample C3005, outer-lateral view (IY381-006); i, MMMC05558, sample C3006, inner-lateral view (IY381-007); j-m, *Panderodus unicostatus* (Branson and Mehl, 1933); j–k, sub-symmetrical, graciliform element (qg); j, MMMC05559, sample C3004, outer-lateral view (IY381-012); k, MMMC05560, sample C3005, postero-outer-lateral view (IY381-017); l-m, falciform (pf) element; l, MMMC05561, sample C3005, inner-lateral view (IY381-013); m, MMMC05562, sample C3005, outer-lateral view (IY381-016); n, *Pelekysgnathus* sp., sub-symmetrical element, MMMC05563, sample C3006, posterior view (IY381-010). Scale bars = 100 μm.

can only be distinguished from *P. exigua exigua* by having a more restricted basal cavity. The occurrence of *P. exigua* in the samples from the NPM-GD871 drill core section is crucial for age determination, but the specimens available are difficult to assign at the subspecies level as the basal cavity is only partially preserved in the specimens available. However, their general morphology, particularly the shape, size and number of denticles of the prominent anterior denticle set, and development of the small basal cavity lobes, is closer to that of *P. exigua philipi*.

Pandorinellina exigua philipi is widely distributed and age diagnostic, with a stratigraphic

range extending from the upper Lochkovian (*pesavis* Biozone) to upper Emsian (*patulus* Biozone) (Farrell, 2004, fig. 8). In eastern Australia, it has been recorded from the Cavan Bluff (Pragian) and Taemas (Emsian) Limestones (Pedder et al., 1970), Roxburgh Formation (Colquhoun, 1995), Garra Formation (Wilson, 1989; Farrell, 2004), the lower Cunningham Formation (Talent and Mawson, 1999), Trundle Group (Pickett and McClatchie (1991; Mathieson et al., 2016) and an unnamed Lower Devonian stratigraphic unit in the southern Thomson Orogen (Zhen et al., 2017) of New South Wales, from the Buchan Caves Limestone (Mawson et al., 1992) and Waratah Limestone (Bischoff and Argent, 1990) in Victoria, and from the Ukalunda Formation of central Queensland (Mawson and Talent, 2003).

The presence of *Pandorinellina exigua* in the sampled intervals of the NPM-GD871 drill core section indicates a maximum age of latest Lochkovian and a minimum age of Emsian. The two illustrated specimens representing the Pa element of this species (Fig. 3h-i) are both broken, but are morphologically comparable with the types of *P. exigua philipi* from Royal Creek (Pragian *sulcatus* Biozone) in the Yukon territory, Canada (Klapper, 1969), and those of the same age from the Karheen Formation in southeastern Alaska (Savage, 1977), from the Nahkaoling Formation (Pragian) of South China (Lu et al., 2016), and from the Jerula Limestone Member of the Gleninga Formation (Trundle Group) illustrated by Pickett and McClatchie (1991, figs 2B–C, E, F, H) from several localities west of Fifield, and by Mathieson et al. (2016, fig. 31A–F) from a roadside locality (float) some 13 km north of Trundle township in central western New South Wales. The higher anterior third of the blade in the type material of *P. exigua philipi* bears four to seven denticles (Klapper, 1969, pl. 5, figs 1–7), but only four in the material from Alaska (Savage, 1977, pl. 1, figs 33–34). Material assigned to this subspecies from eastern Australia varies from two to four denticles, such as in the samples from Trundle (Mathieson et al., 2016, fig. 31A–F) and those from the Garra Formation (Farrell, 2004) of New South Wales. The specimens from the NPM-GD871 drill core section have two or three denticles on the higher anterior third of the blade (Fig. 3h–i).

CORAL AND STROMATOPOROID ASSEMBLAGE

One rugose coral species, *Microplasma ronense* (Mansuy, 1913), three tabulate coral species, *Favosites duni* Etheridge, 1920, *Squameofavosites bryani* (Jones, 1937) and *Thamnopora minor* Jones, 1941, and a poorly preserved stromatoporoid species were recovered from the same stratigraphic level (Litho-unit 5) in association with conodont sample C3004 (Fig. 2, Table 1). The cystiphyllid rugose coral *M. ronense* is presented in three thin sections (MMF46840a, MMF46840b, MMF46841a; Fig. 4a–d). This species was originally reported from the Emsian or lowermost Eifelian of the Ron region in Vietnam and Laos, south-eastern Asia (Mansuy, 1913; Fontaine, 1961). It has been widely reported in eastern Australia, with a stratigraphic range from the Pragian to Emsian (Zhen 1995; Blake 2010). The specimens have a corallite diameter varying from 5 to 9 mm, thin corallite walls without observable stereozones, and the rare occurrence of short septal spines on the upper surface of dissepiments (Fig. 4a, c, e). They are comparable with those illustrated by Hill (1942) from the Garra Formation exposed near Wellington, central-west New South Wales.

In eastern Australia tabulate coral *Favosites duni* has a stratigraphic range restricted to the Lower Devonian (Etheridge, 1920; Jones, 1941; Hill, 1950; Hill et al., 1967; Jell and Hill, 1970; Blake, 2010). In the current collection, it occurs in five thin sections (MMF46839-a, MMF46841b, MMF46842a, MMF46844a and MMF46844b; Fig. 5a–c), as small hemispherical to irregularly globular or ramose coralla with a diameter of 20–25 mm. Lage corallites typically have 5 to 7 sides and are 1.0–2.2 mm in diameter (mean 1.6 mm), and are surrounded by smaller corallites 0.5 to 0.9 mm in diameter with typically 3 or 4 walls . They are comparable with those recorded from the Lower Devonian (Erebus beds) of eastern-central Queensland (Blake, 2010) in having the same range of corallite sizes, 20 to 22 horizontal tabulae per 10 mm longitudinally, thin corallite walls (0.1–0.15 mm), absence of visible mural pores in longitudinal sections and the rare occurrence of short septal spines. The type material of this species is from the Lower Devonian of Cavan near Yass, southern New South Wales (Etheridge, 1920). It has also been reported from the Douglas Creek Limestone (Emsian) of Queensland (Jones, 1941; Hill et al., 1967; Jell and Hill, 1970) and the Murrindal Limestone (Emsian) of Victoria (Hill, 1950), and shows wide variation in corallite size and density of tabulae. *Favosites forbesi* Milne-Edwards & Haime, 1851 resembles *Favosites duni* in having dimorphic corallites, but with large corallites that are slightly larger in size (2–3 mm) and mural pores that are better developed and commonly seen in longitudinal sections (Hill and Jones 1940; Philip, 1962; Blake, 2010).
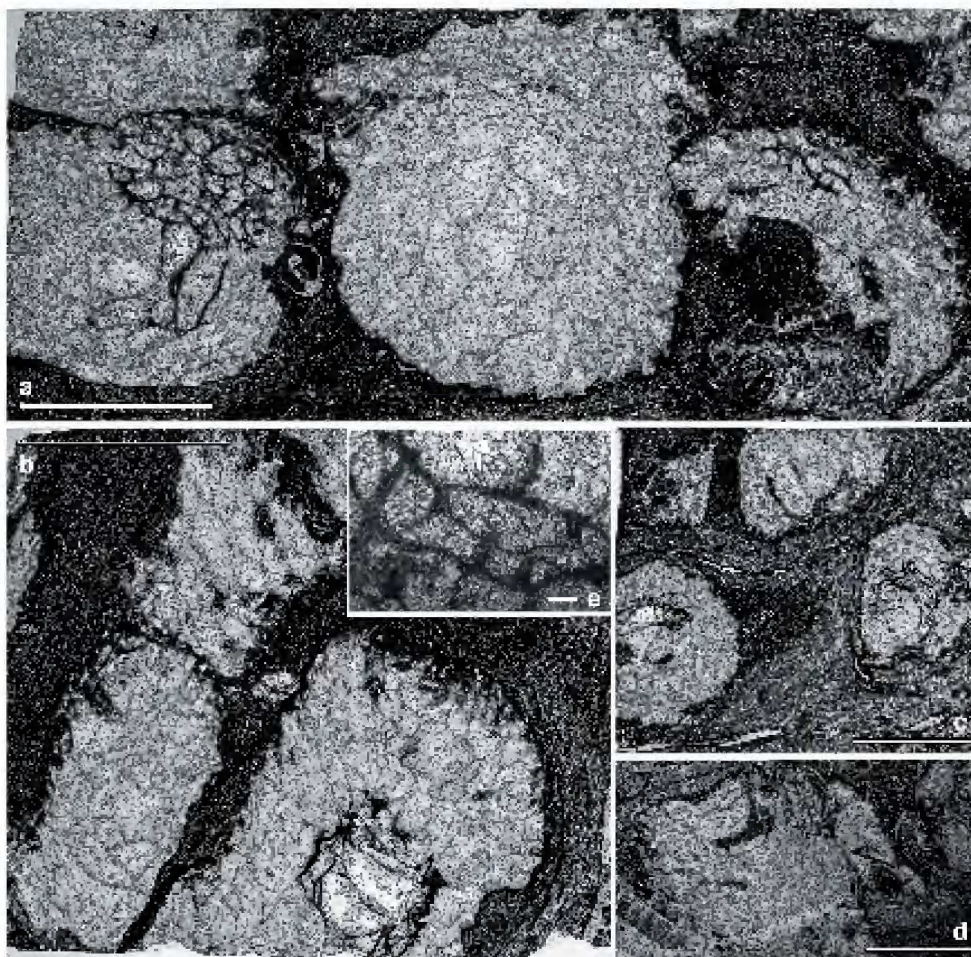
Figure 4. Rugose coral *Microplasma ronense* (Mansuy, 1913) from the unnamed stratigraphic unit (Litho-unit 5) intersected in the NPM-GD871 drill hole; a, MMF46840b-1, TS; b, MMF46840a, LS; c, MMF46841a, TS; d, MMF46841a, TS; scale bars = 5 mm; e, MMF46840b-1, TS, close-up, showing septal spines, scale bar = 0.2 mm.

Tabulate coral *Squameofavosites bryani* has been widely reported from the Lower and Middle Devonian of eastern Australia (Blake, 2010). In the material from drill hole NPM-GD871 (Fig. 2), this species occurs in two thin sections (MMF46838a and MMF46838b; Figs 6–7) prepared from a small foliose corallum. This specimen is identical with the types from the Taemas Limestone (Emsian) at Good Hope, near Yass (Jones, 1937), and those documented from the Cookeys Plains Formation of central western New South Wales (Földvary, 2001) and from the Emsian Craigilee beds and Erebus beds of Queensland (Blake, 2010), in having comparable size of corallites (1–1.5 mm, mean 1.2 mm), moderately thick walls (0.2–0.28 mm in thickness), closely-spaced tabulae (30–36 per 10 mm), mural pore size (0.2–0.27 mm), and abundant occurrence of squamulae that are short and triangular in outline with a thick base, and are paired in neighbouring corallites immediately above mural pores (Fig. 6a–b). However, the mural pores are more abundant and spaced more closely (20–25 per 10 mm) in the current specimen, typically in single or double
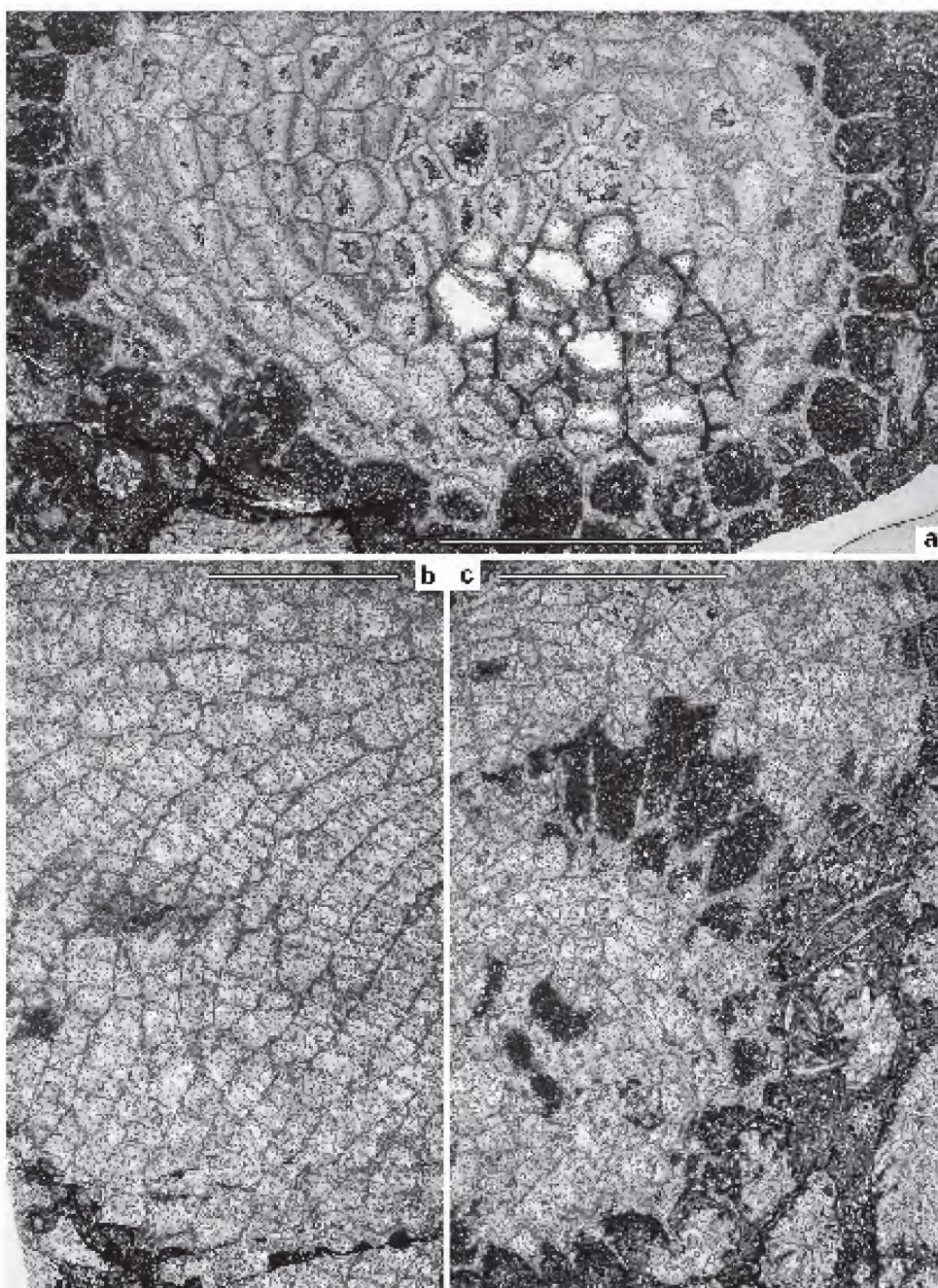
Figure 5. Tabulate coral *Favosites duni* Etheridge, 1920 from the unnamed stratigraphic unit (Litho-unit 5) intersected in the NPM-GD871 drill hole; a, MMF46842a, TS; b, MMF46841b, LS; c, MMF46839-1, TS + LS; scale bars = 5 mm.
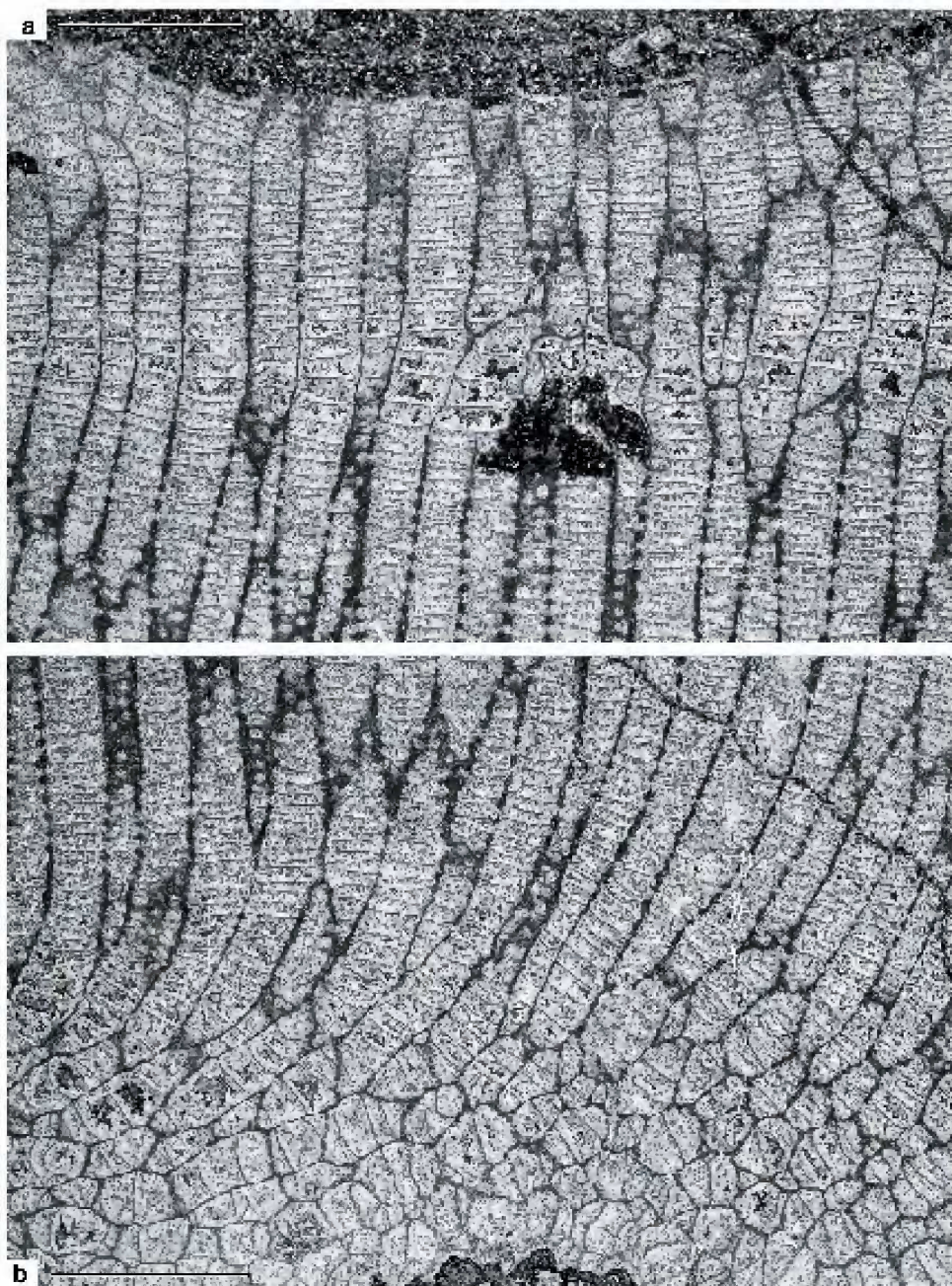
Figure 6. Tabulate coral *Squameofavosites bryani* (Jones, 1937) from the unnamed stratigraphic unit (Litho-unit 5) intersected in the NPM-GD871 drill hole; MMF46838b; a, LS; b, TS + LS; scale bars = 5 mm.
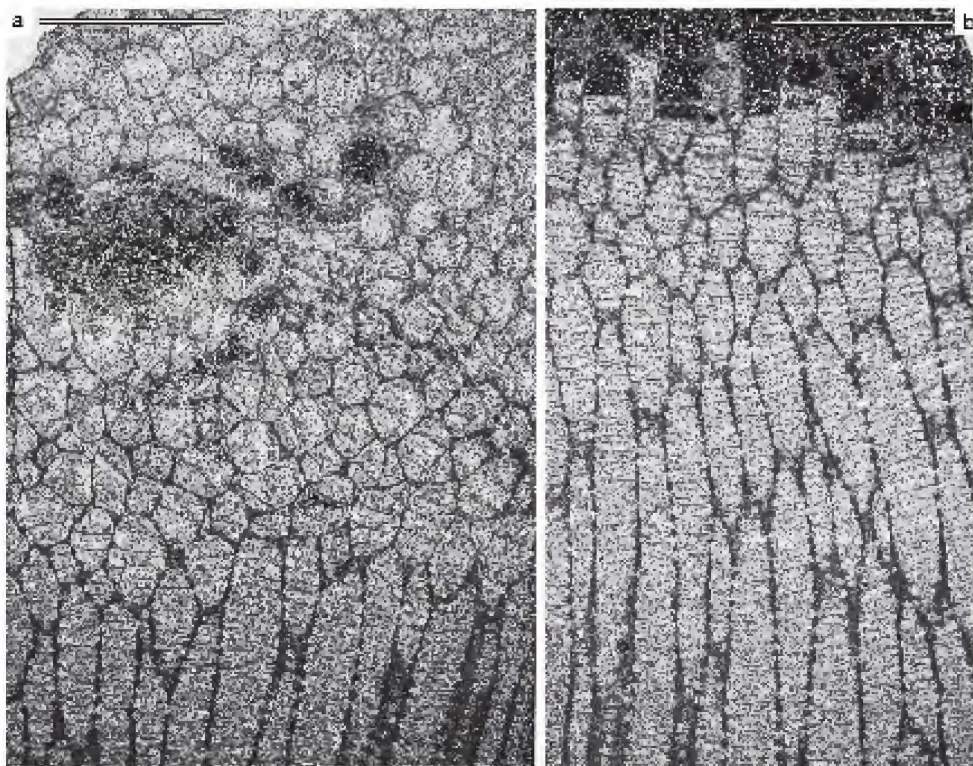
Figure 7. Tabulate coral *Squameofavosites bryani* (Jones, 1937) from the unnamed stratigraphic unit (Litho-unit 5) intersected in the NPM-GD871 drill hole; MMF46838a, a, TS+LS, b, LS, scale bars = 5 mm.

rows (rarely in three rows). In longitudinal sections mural pores are evenly spaced with the neighbouring two rows arranged in alternating horizons (Fig. 6b).

Tabulate coral *Thamnopora minor* (Fig. 8a-d) is the most abundant coral species observed in a nearly six m interval (from 90.8 m to 96.38 m) of the NPM-GD871 drill core section. Coralla are randomly distributed and form several bands of so-called "spaghetti rock" where fragmentary branches are closely packed and in contact (Fig. 8a-b). The coralla are slender (1.8 to 3 mm in diameter) with corallites of 0.2 (axially) to 0.3 mm (distally) in diameter. Rounded corallites with thick walls, well-developed growth lamination and a median suture between corallites (Fig. 8c-d) confirm assignment to *Thamnopora*. Growth form and the general morphology and sizes of coralla and corallites are identical with the syntypes of this species from the Douglas Creek Limestone (Emsian) of Queensland (Jones, 1941; Pickett, 2010). *Thamnopora minor*

shows some resemblance to *Thamnopora angulata* Hill, 1950, from the Murrindal Limestone (Emsian) of Victoria, but the Victorian species has slightly larger coralla (4 mm in diameter) and corallites (diameter 0.3 mm axially and 1.5 mm distally). *Thamnopora minor* Dubatolov, 1959 reported from the Middle Devonian of Russia and Vietnam is treated herein as a homonym of *Thamnopora minor* Jones, 1941.

The single stromatoporoid specimen is a small domal skeleton with fine microreticulate structure (Fig. 9a–b). Its microcolliculi are aligned to form a recognizable horizontal structure and suggests that it belongs to a species of *Densastroma*, but poor preservation makes further identification impossible. However, *Densastroma* is only known from the Silurian. In New South Wales, it was previous recorded as *Densastroma pexisum* (Yavorsky, 1929) by Birkhead (1976) from the Mirrabooka Formation (Wenlock to Ludlow) at Cheesemans Creek near Orange. Abundant specimens of this species have
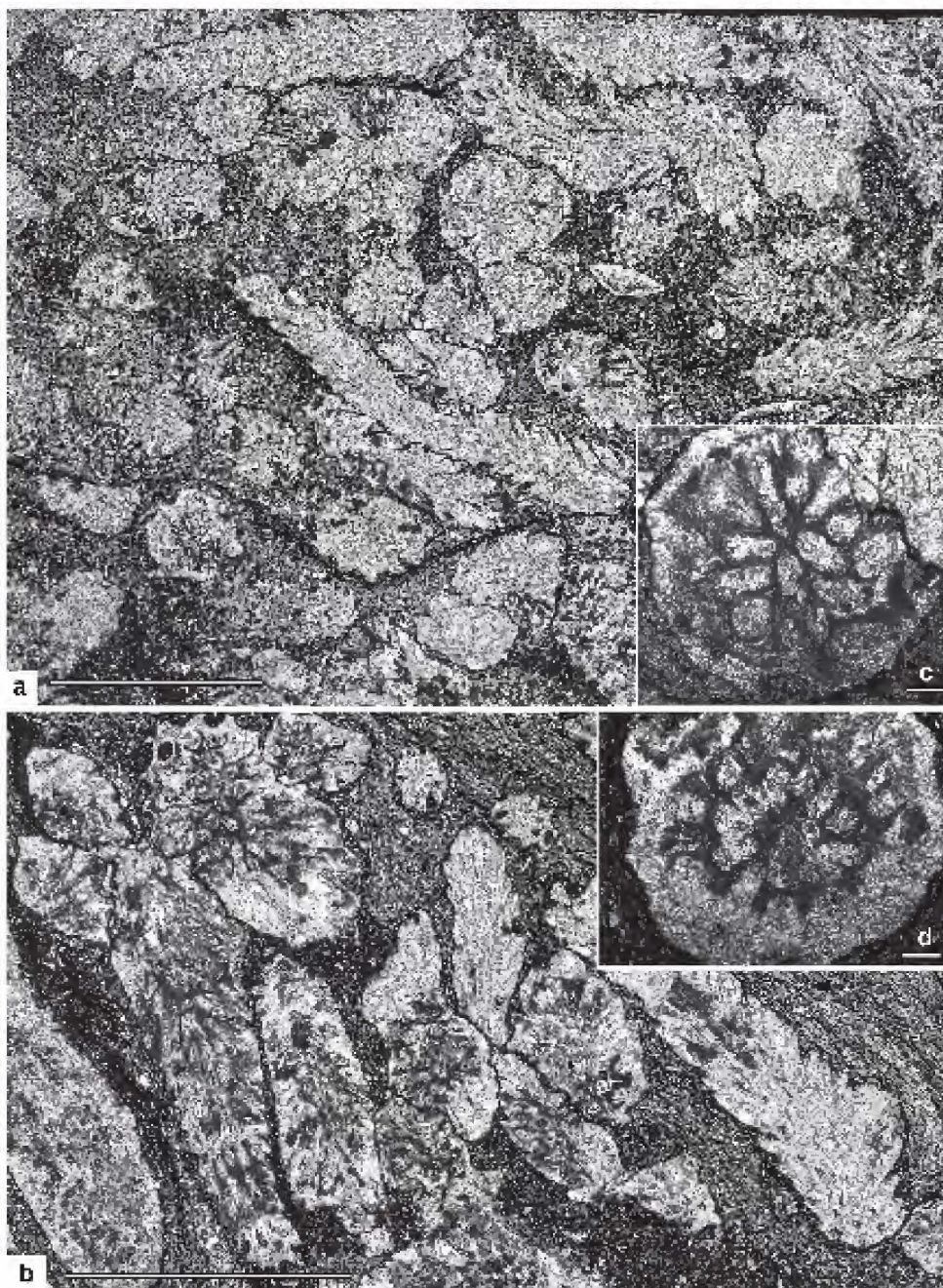
Figure 8. Tabulate coral *Thamnopora minor* Jones, 1941 from the unnamed stratigraphic unit (Litho-unit 5) intersected in the NPM-GD871 drill hole; a, MMF46839-2; b, MMF46840b-2, scale bars = 5 mm; c, MMF46839-2a, TS, d, MMF46840b-2a, TS, close-up, showing growth lamination and median suture between corallites, scale bar = 0.2 mm.
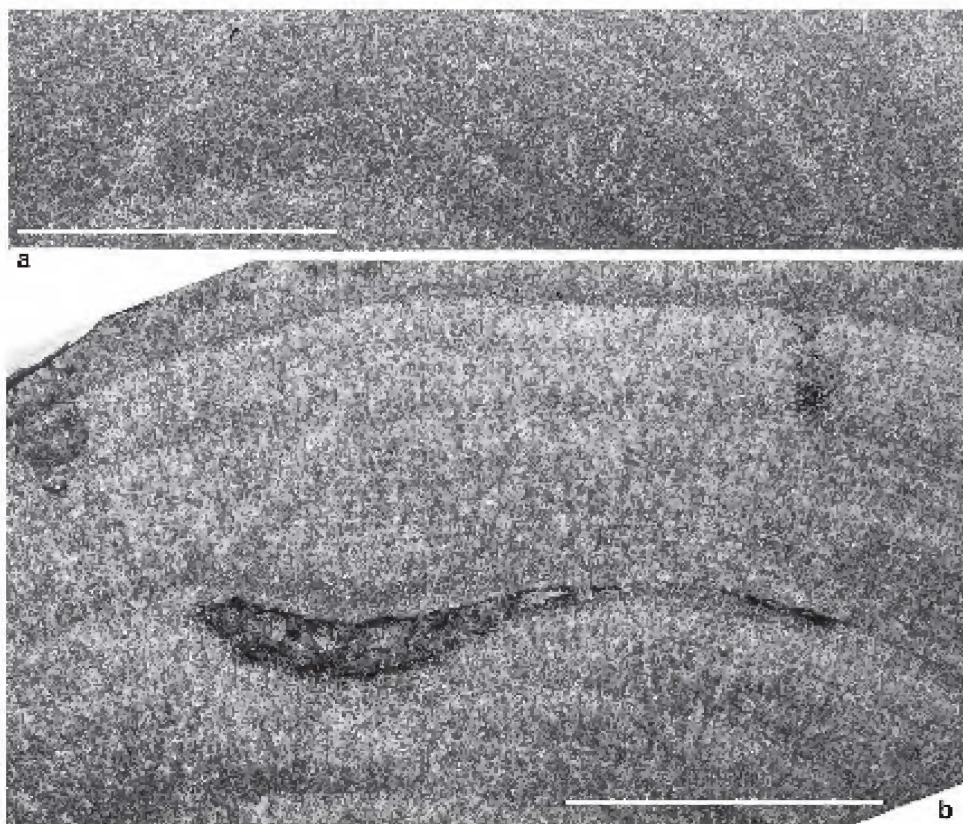
Figure 9. Stromatoporoid *Densastroma* sp. from the unnamed stratigraphic unit (Litho-unit 5) intersected in the NPM-GD871 drill hole; a, MMF46844b, tangential section; b, MMF46844a, vertical section; scale bars = 5 mm.

also been recovered from the Narragal Limestone (Ludlow) of central-west New South Wales (Webby and Zhen, unpublished material). Specimens doubtfully assigned to *Densastroma* were previously reported from the Derriwong Group at Myola Station, 2.5 km southwest of Trundle (Pickett and Ingpen, 1990, table 1) and at a site about 15 km west of Fifield (Pickett and McClatchie, 1991, p. 16).

The late Silurian age suggested by this stromatoporoid specimen contradicts the Early Devonian age derived from the associated conodonts and corals as discussed above. It seems probable that this specimen has been reworked, which is consistent with the detrital nature of the limestone (Litho-unit 5) at the base of the unit, immediately above the unconformity (Fig. 2).

DISCUSSION ON REGIONAL BIOSTRATIGRAPHIC CORRELATION

The Derriwong Group, previously the Derriwong Beds of Raggatt (1936), was defined to include the basal Edols Conglomerate and quartzose sandstone (the Calarie Sandstone), volcanics in the lower part (e.g. Byong Volcanics) and laminated siltstone and fine to medium sandstone, mudstone (or marl) and minor limestone lenses in the upper part (the Cookeys Plains Formation) with an age ranging from the Přídolí (late Silurian) to Pragian (Early Devonian) (Sherwin, 1980, 1996). Sherwin (1980) gave a total estimated thickness of ca 2700 m for the Derriwong Group exposed in the Mineral Hill-Trundle-Peak Hill area, but admitted that the thickness was difficult to measure because of poor and very patchy outcrops in the region. Largely for this same reason, the internal biozonal subdivision and regional correlation of this unit is yet to be established.

The maximum age (Přídolí) of the Derriwong Group was based on studies of conodonts and corals from the area southwest of Trundle (Pickett and Ingpen, 1990) and the area west of Fifield (Pickett and McClatchie, 1991) on the western flank of the Tullamore Syncline, confirmed by the occurrence of conodont species including *Ozarkodina crispa* (Walliser, 1964), *Ozarkodina confluens* (Branson and Mehl, 1933), *Coryssognathus dubius* (Rhodes, 1953) and *"Ozarkodina" eosteinhornensis* (Walliser, 1964). Földvary (2001, 2006) reported a diverse fauna including corals, stromatoporoids, brachiopods and trilobites from the Cookeys Plains Formation exposed in the Bogan Gate-Trundle-Mineral Hill area. The type material of the stromatoporoid species *Plexodictyon conophoroides* (Etheridge, 1921) is from the Cookeys Plains Formation exposed ca 5 km SW of Trundle (Pickett and Ingpen, 1990, p. 11; Földvary, 2001, Locality X). Two topotypes of this species were also illustrated by Földvary (2001, fig. 4.1–4.4). *Plexodictyon* is a distinctive stromatoporoid genus restricted to the Silurian and possibly Upper Ordovician and is widely distributed in Australia, Asia, Europe and North America.

Zhen et al. (2017, fig. 7a–g) reported the presence of the conodont *Caudicriodus woschmidti* (Ziegler, 1960) in several spot samples from the Derriwong Group north of the Mordialloc copper mine, ca 7 Km NNE of Trundle on the western flank of the Tullamore Syncline. *Caudicriodus woschmidti* also occurs in one (C0925, Fig. 10j–k) of the spot samples collected from outcrops mapped as Cookeys Plains Formation exposed ca 10 km NE of Bogan Gate on the eastern flank of the Tullamore Syncline. *Caudicriodus woschmidti* is the nominal species defining the *Caudicriodus woschmidti* conodont Biozone at the base of the Devonian, indicating that the Silurian/Devonian boundary is within the Derriwong Group.

Several samples (C1725 and C0923) from the Cookeys Plains Formation exposed ca 10 km NE of Bogan Gate yielded *Pandorinellina exigua exigua* (Philip, 1966) (Fig. 10a–d), which has a stratigraphic record extending from the latest Pragian (the *pireneae* Biozone) to Emsian (the *serotinus* Biozone) (see Farrell, 2004). Co-occurrence of *P. exigua exigua* and *Ozarkodina selfi* Lane & Ormiston, 1979 (Fig. 10e–i) in some of the samples (e.g. C1725) from outcrops mapped as Cookeys Plains Formation, ca 10 km NE of Bogan Gate, suggest that the minimum age of this unit is late Pragian (the *pireneae* Biozone) rather than early Lochkovian as suggested by previous authors (e.g. Sherwin, 1996; Földvary, 2001). At its type locality in eastern Alaska, *Ozarkodina selfi* has a stratigraphic range restricted to the Pragian (from

sulcatus to *pireneae* biozones), in the lower part of the Salmontrout Limestone (Lane and Ormiston, 1979). In New South Wales, it was reported from the Mountain Dam Limestone by Mathieson et al., 2016, (referred to as three new subspecies), the White Tank Limestone Member of the Meryula Formation within the Cobar Supergroup (Pickett, 1980), and the Nubrigyn Member of the Cunningham Formation (Talent and Mawson, 1999).

The Wallingalair Group, on the eastern flank of the Tullamore Syncline to the immediate west of the study area (Pearce Prospect; Fig. 1), consists of a lower unit (the Connardoo Sandstone) of medium-coarse grained sandstone and minor conglomeratic sandstone at the base, and an upper unit (the Beugamel Sandstone) of medium-coarse grained quartzose sandstone. The two separated by a flaggy siltstone and fine grained sandstone unit (the Euchabil Gap Formation). Unfortunately, a direct contact relationship between the Derriwong Group and the overlying Wallingalair Group is obscured in the area. The precise age of the Wallingalair Group is still uncertain because of its poor fossil record. Sherwin (1994, p. 30; 1996, p. 64) correlated the base of the Wallingalair Group with that of the Trundle Group, based mainly on the occurrence of a brachiopod species considered to resemble *Howellella jaqueti* (Dun, 1898) from the Coonardoo Sandstone. However, conodonts including *Zieglerodina remscheidensis* (Fig. 11i–l), *Amydrotaxis druceana* (Pickett, 1980) (Fig. 11d–h) and *P. exigua exigua* (Fig. 11a–c) from a limestone sample collected near the base of the Wallingalair Group 4.4 km ESE of Bogan Gate railway station (sample C0785, see Pickett, 1983; likely an allochthonous limestone clast), confirm the minimum age (late Pragian) for the top of the Derriwong Group as discussed above. *Amydrotaxis druceana* (Fig. 11d–h) has a stratigraphic range restricted to the middle Lochkovian (*delta* Biozone) to Pragian (*pireneae* Biozone) (Farrell, 2004, fig. 6). It is widely distributed in New South Wales, recorded from the lower part of the Garra Formation (Druce, 1970; Farrell, 2004), the Boomerang Tank Limestone Member of the Baledmund Formation, the Mountain Dam Limestone, the White Tank Limestone Member of the Meryula Formation and the Rookery Limestone Member of the Meryula Formation within the Cobar Supergroup (Pickett, 1980; Mathieson et al., 2016), and from the lower Cunningham Formation (Talent and Mawson, 1999). It was also reported from the Lilydale Limestone (Wall et al., 1995) and other Pragian limestones (Mawson and Talent, 1994) of Victoria.
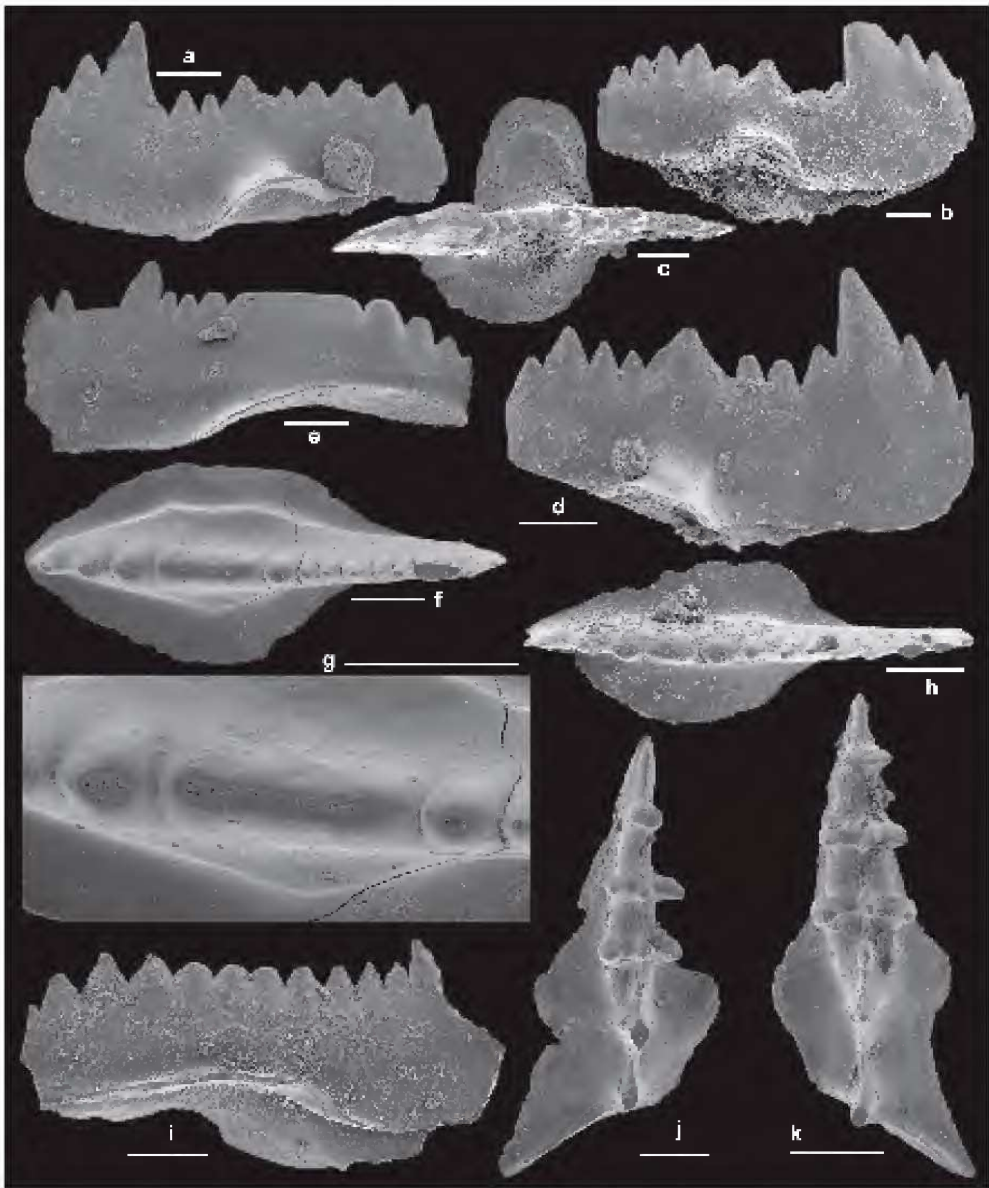
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Figure 10. Early Devonian conodonts from the Derriwong Group exposed NE of Bogan Gate; a–d, *Pandorinellina exigua exigua* **(Philip, 1966) from sample C1725; Pa element; a, MMMC05564, outer-lateral view (IY385-003); b, MMMC05565, outer-lateral view (IY385-001); c, MMMC05566, apical view (IY385-002); d, MMMC05567, inner-lateral view (IY385-011); e–i,** *Ozarkodina selfi* **Lane & Ormiston, 1979 from sample C1725; e, MMMC05568, outer-lateral view (IY385-007); f–g, MMMC05569, f, apical view (IY385-005), g, close-up view showing cross section of denticles (IY385-006); h, MMMC05570, apical view (IY385-009); i, MMMC05571, inner-lateral view (IY385-008); j-k,** *Caudicriodus woschmidti* **(Ziegler, 1960) from sample C0925; j, MMMC05572, apical view (IY385-015); j, MMMC05573, apical view (IY385-016). Scale bars = 100 µm.**
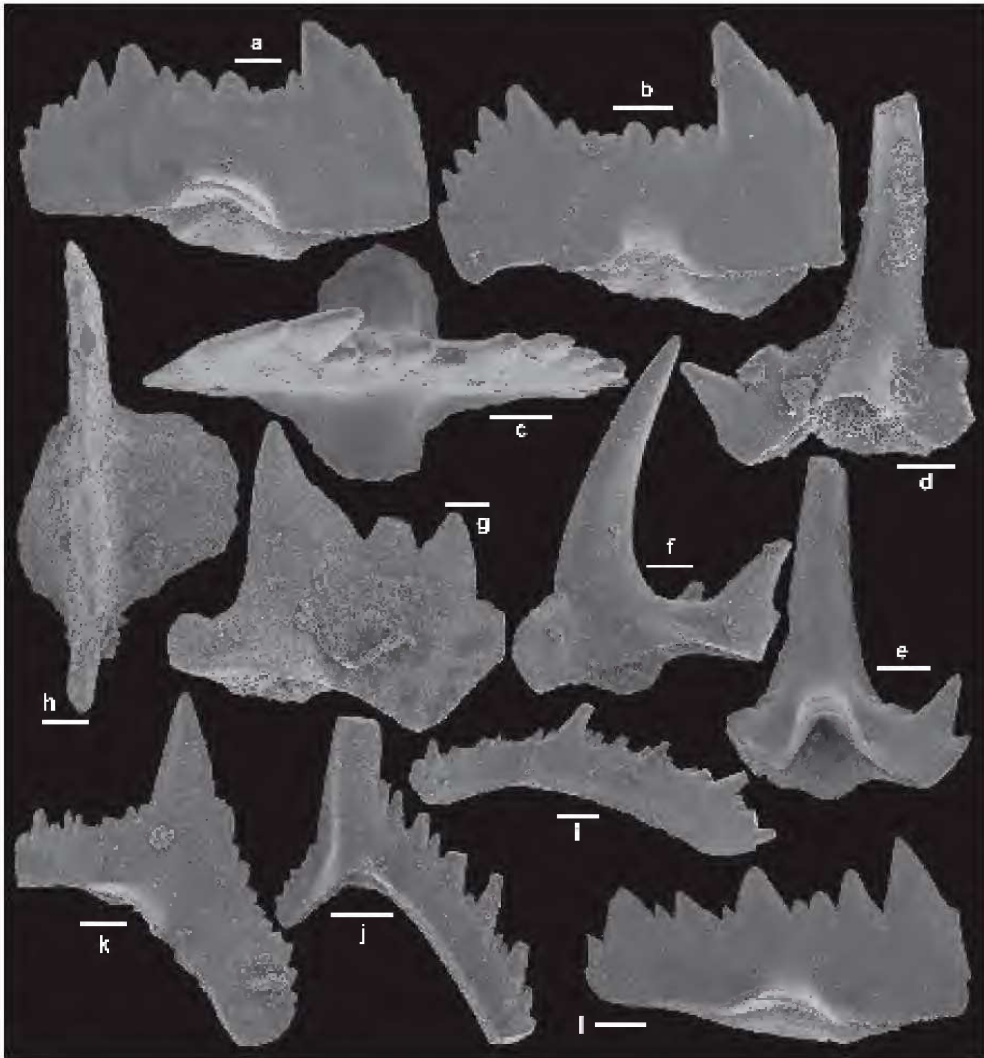
Figure 11. Early Devonian conodonts from a possibly allochthonous limestone clast (sample C0785) near base of the Wallingalair Group exposed 4.4 km ESE of Bogan Gate railway station; a–c, *Pandorinellina exigua exigua* **(Philip, 1966), Pa element; a, MMMC05574, outer-lateral view (IY395-005); b, MMMC05575, outer-lateral view (IY395-002); c, MMMC05576, apical view (IY395-001); d–h,** *Amydrotaxis druceana* **(Pickett, 1980); d–e, Sa element, d, MMMC05577, posterior view (IY395-014); e, MMMC05578, posterior view (IY395-013); f, Sc element, MMMC05579, inner-lateral view (IY395-015); g, Pb element, MMMC05580, inner-lateral view (IY395-012); h, Pa element, MMMC05581, apical view (IY395-016); i–l,** *Zieglerodina remscheidensis* **(Ziegler, 1960); i, Sc element, MMMC05582, inner-lateral view (IY395-011); j, M element, MMMC05583, posterior view (IY395-010); k, Pb element, MMMC05584, inner-lateral view (IY395-008); l, Pa element, MMMC05585, outer-lateral view (IY395-006). Scale bars = 100 μm.**

Therefore, on faunal grounds the unnamed fossiliferous bioclastic limestone with a carbonaceous black mudstone matrix intersected in NPM-GD871 can be correlated with the upper part of the Derriwong Group and the upper part of the Trundle Group (or Yarra Yarra Creek Group) exposed in the area farther west.

Th CAI 4 temperature range is sub-greenschist facies which has important implications for future mineral exploration in the Northparkes district, particularly 'greenrock' alteration vectoring studies (Cooke et al., 2014; Wilkinson et al., 2015). The observed temperature range is consistent with the current tectonic and structural models, which indicate that the Goonumbla Volcanic Complex that hosts the Northparkes porphyries acted as an inert block that portioned strain and remained largely unaffected by deformation (Scheibner and Basden, 1996). The age and maximum temperature indicated by the CAI suggest that the partition of strain around the Northparkes district continued through the Devonian, meaning all epidote samples could be considered to have a hydrothermal origin, making them reliable indicators of mineralising potential in the district (Cooke et al., 2014).

CONCLUSIONS

The unnamed stratigraphic unit with a total apparent thickness of 35 m (Litho-units 4 and 5) intersected in the NPM-GD871 is age correlative with the upper part of the Derriwong Group exposed on the eastern flank of the Tullamore Syncline and with the upper part of the Trundle Group (or Yarra Yarra Creek Group) exposed in the area farther west.

Available conodont data suggest that the Derriwong Group on the eastern flank of the Tullamore Syncline has a minimum age of the late Pragian. Identical conodont faunas from the upper part of the Derriwong Group and from reworked limestone clasts near the base of the overlying Wallingalair Group on the eastern flank of the Tullamore Syncline provide further support for this age determination of the Derriwong Group in the area.

The Wallingalair Group, consisting of predominantly medium-coarse grained sandstone and conglomeratic sandstone at the base, represents a regressive cycle of deposition under marginal marine and fluvial conditions with minor open marine incursions. The faunal relationship documented in this study shows that this sandstone unit is younger than the Trundle or the Yarra Yarra Creek groups exposed in the area farther west, rather than correlative as previously thought.

The contact relationship between the unnamed Early Devonian carbonate unit (Litho-units 4 and 5) and unconformably underlying diorite breccia and Ordovician volcanic rocks intersected in the NPM-GD871 shows that the unconformity defining the base of the Derriwong Group in the region is diachronous. The study area (the Pearce Prospect) within the Northparkes porphyry district was palaeogeographically located on an Ordovician volcanic island, which had likely experienced an extended period of exposure and so was subjected to erosion and weathering during the Silurian and earliest Devonian, and then became submerged during the maximum flooding of the region in the Pragian.

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